BBSR

STANDARDS DEVELOPMENT BRANCH OMOE
3693600007623

Environment Canada | Environnement Canada

Ontario Agreement on Great Lakes Water Quality

Ontario Ministry of the Environment

Unslaked Lime - Its Direct Use in Phosphorus Removal Processes

Research Report No. 105

TD
758.5
.P56
U57
1980
MOE

...ch Program for the Abatement of Municipal Pollution
...der Provisions of the Canada-Ontario Agreement
on Great Lakes Water Quality

Copyright Provisions and Restrictions on Copying:

This Ontario Ministry of the Environment work is protected by Crown copyright (unless otherwise indicated), which is held by the Queen's Printer for Ontario. It may be reproduced for non-commercial purposes if credit is given and Crown copyright is acknowledged.

It may not be reproduced, in all or in part, part, for any commercial purpose except under a licence from the Queen's Printer for Ontario.

For information on reproducing Government of Ontario works, please contact Service Ontario Publications at copyright@ontario.ca

CANADA-ONTARIO AGREEMENT

RESEARCH REPORTS

These RESEARCH REPORTS describe the results of investigations funded under the Research Program for the Abatement of Municipal Pollution within the provisions of the Canada-Ontario Agreement on Great Lakes Water Quality. They provide a central source of information on the studies being carried out in this program through in-house projects by both Environment Canada and the Ontario Ministry of Environment, and contracts with municipalities, research institutions and industrial organizations.

Inquiries pertaining to the Canada-Ontario Agreement RESEARCH PROGRAM should be directed to -

Wastewater Technology Centre
Canada Centre for Inland Waters
Environment Canada
P.O. Box 5050
Burlington, Ontario L7R 4A6

Ontario Ministry of Environment
Pollution Control Branch
135 St. Clair Avenue West
Toronto, Ontario M4V 1P5

TD
758.5
.P56
U57
1980

Unslaked lime : it's direct use in phosphorus removal processes /

78922

BBSR

UNSLAKED LIME - ITS DIRECT USE IN PHOSPHORUS REMOVAL PROCESSES

by the

Wastewater Technology Centre
Environmental Protection Service
Environment Canada

RESEARCH PROGRAM FOR THE ABATEMENT
OF MUNICIPAL WATER POLLUTION WITHIN
THE PROVISIONS OF THE CANADA-ONTARIO
AGREEMENT ON GREAT LAKES WATER QUALITY

Project No. 71-3-1

This document may be obtained from -

Training and Technology Transfer
Division (Water)
Environmental Protection Service
Environment Canada
Ottawa, Ontario
K1A 1C8

Ontario Ministry of the Environment
Pollution Control Branch
135 St. Clair Avenue West
Toronto, Ontario
M4V 1P5

© Minister of Supply and Services Canada 1980
Cat. No. En 43-11/105E
ISBN 0-662-11334-9
BEAUREGARD PRESS LIMITED

ABSTRACT

This study, designed to evaluate the use of quicklime for phosphorus removal, was supported under the Canada-Ontario Agreement on Great Lakes Water Quality.

The study was carried out in a 1.5 L/s (20 Igpm) pilot plant operated at the Wastewater Technology Centre. The experimental work occurred over a seven month period from October, 1972 to April, 1973.

The study determined that quicklime may be used in place of hydrated lime without an increase in the lime requirement provided that the lime slaking temperature was within 60 to 82°C and the water/quicklime ratio (weight basis) 6 to 10 at a slaking reactor detention time range of 5 to 50 minutes.

A quicklime feed preparation system was developed and the full scale system design is presented.

RÉSUMÉ

La présente étude sur l'utilisation de chaux vive à des fins de déphosphatation a été financée en vertu de l'Accord Canada-Ontario sur la qualité de l'eau des Grands lacs.

Elle a été réalisée dans une unité pilote d'un débit de 1,5 l/s (20 gallons imp./min), au Centre technique des eaux usées, d'octobre 1972 à avril 1973 inclusivement.

La chaux vive peut remplacer une quantité égale de chaux éteinte à condition que la température d'extinction soit maintenue entre 60 et 82°C, que le rapport pondéral eau/chaux vive soit de 6 à 10 et que la durée de l'extinction soit de 5 à 50 min.

Une dispositif de préparation de la chaux vive a été mis au point, et il est présenté à l'échelle.

TABLE OF CONTENTS

		Page
ABSTRACT		i
TABLE OF CONTENTS		iii
	List of Figures	iv
	List of Tables	v
CONCLUSIONS		vi
1	INTRODUCTION	1
2	EXPERIMENTAL METHODS	5
2.1	Pilot Plant Equipment	5
2.2	Preliminary Experiments	6
2.3	Pilot Plant Test Procedures	7
2.4	Lime Grades Used in Experiments	7
3	RESULTS AND DISCUSSIONS	11
3.1	Preliminary Experiments	11
3.2	Pilot Plant Tests	13
4	HANDLING OF QUICKLIME FOR PHOSPHORUS REMOVAL	18
4.1	Quicklime Storage	18
4.2	Quicklime Particle Size	18
4.3	Quicklime Reactor	19
4.4	Cost of a Quicklime Feed System	21
REFERENCES		23
ACKNOWLEDGEMENTS		24

LIST OF FIGURES

Figure		Page
1	Chemical Pilot Plant Schematic	5
2	Pilot Scale Quicklime Handling System	6
3	Comparison of Hydrated and Quicklime Dosages in Two Representative Jar Tests	11
4	Effect of Initial Temperature on Slaking Rate	12
5	Relative Slaking Rates of Lime Grades	12
6	Examples of Screen Analyses of Quicklime and Grit	13

LIST OF TABLES

Table		Page
1	Analytical Tests on Process Streams During Quicklime Experiments	8
2	Pilot Plant Conditions for Quicklime Evaluation	8
3	Mesh (Tyler) Analyses of Lime Grades	9
4	ASTM Slaking Rates of Lime Grades	9
5	Characteristics of Main Grades of Quicklime (Carr, 1976)	10
6	Raw Sewage Characteristics	14
7	Quicklime vs. Hydrated Lime Requirement to Achieve Desired pH Level	15
8	Comparison of Removal Characteristics (Phosphorus)	15
9	Comparison of Removal Characteristics (Biochemical Oxygen Demand and Suspended Solids)	16
10	Sludge Production	17
11	Slaking with Wastewaters (Carr, 1976)	20
12	Agitation Requirements	20
13	Lime Requirements vs. Plant Size	22
14	Lime Feed Equipment Cost as a Function of Feed Rate	22

CONCLUSIONS

The following conclusions were drawn from the pilot plant study:

1) To achieve the same pH in the treatment process, 1.25 times by weight of hydrated lime that quicklime is required.
2) The reduction of total phosphorus, soluble phosphorus, biochemical oxygen demand, and suspended solids as a result of treatment was the same, regardless of whether slaked quicklime or hydrated lime was used.
3) Sludge production rates were similar in both cases.
4) All quicklimes tested could be fed satisfactorily from conventional dry feeders.
5) Instances of arching and flooding from the chemical hopper were lessened considerable when quicklime was used.
6) Air slaking was lessened and handling difficulties were reduced as the particle size of the quicklime increased.
7) Grit problems increased with increasing quicklime particle size. There were approximately 3 kg of grit for every 100 kg of quicklime. Grit from minus 10 mesh and minus 28 mesh quicklime was not a problem as it passed to the process with the hydrated lime formed.
8) No problems were encountered with slaking the material in the solution pot. The optimum conditions were:
   - reaction temperature 60 to 82°C,
   - water/quicklime ratio (weight basis) between 6:1 and 10:1,
   - detention time in slaking reactor 5 to 50 minutes.
9) Build-up of lime on side walls in the dissolving tank was reduced when quicklime was used. Periodic cleaning was required.

1 INTRODUCTION

The technology for removal of phosphorus from wastewater has developed rapidly in the last few years as a result of concern arising from the over-fertilization, and thus eutrophication, of surface waters. Establishment of water quality standards that limit the concentration of phosphorus entering receiving waters has followed this improved treatment technology. Research and demonstration studies at several cities in the past few years have contributed to the advance in knowledge of phosphorus removal (Convery, 1970; Menar and Jenkins, 1972; Sheehy and Evans, 1976). Several chemical coagulants have been shown to be compatible with primary settling and biological systems while at the same time achieving high phosphorus removal efficiencies. Those chemicals which show most promise include aluminum sulphate, ferric chloride/sulphate and calcium hydroxide.

The addition of lime to raw wastewater is practised at a number of waste treatment plants (Bernhoff, 1974). The removal of phosphorus by lime in the primary treatment stage is accompanied by increased BOD and suspended solids removal, which leads to a reduction in the organic load on the secondary treatment facilities (Black and Lewandowski, 1969). Reduced organic loadings benefit overloaded plants and aid in increasing the degree of nitrification. Other benefits derived from lime use include improved oil, grease and scum removal, and lower corrosion rates in the primary sludge handling system. The main disadvantage of using lime for phosphorus removal has been the increased quantity of primary sludge that results. For most primary plants, it is anticipated that the sludge volume produced in the primary stage will be three times what is normally produced in the absence of lime addition. This is not as bad as it seems as one-half of the increased sludge volume can be attributed to increased suspended solids removal. Also, as the load to the activated sludge section of the process is reduced by about 50%, the quantity of waste activated sludge produced (which is difficult to dewater) is reduced accordingly (Minton and Carlson, 1973).

There are three possible methods for storage and feeding of lime in full-scale sewage treatment operations:

1) bag or bulk hydrated lime batch slurry make-up, storage and controlled rate feeding;
2) dry hydrated lime bulk hopper storage, batch continuous slurry make-up and controlled feed rate; or,

3) dry quicklime bulk hopper storage, batch or continuous slaking, slurry storage and controlled feeding (Fahlenbock, 1973; National Lime Association, 1976).

Considerable operational savings can be realized through the use of quicklime instead of hydrated lime. The theoretical ratio of calcium oxide in quicklime to that in the hydrate is 1.33 to 1.0, or, stated in another way, 75 kg of quicklime should be as effective as 100 kg of hydrate. Quicklime is also about 5 percent lower in price per kg than hydrated lime. In addition (and probably more importantly), the improved flowability of quicklime in comparison with hydrated lime greatly reduces handling problems (Hirsch, 1962).

Quicklime may be divided into three classes on the basis of physical and chemical properties: high calcium quicklime (less than 5% magnesium oxide); magnesium quicklime (5 to 35% magnesium oxide); and dolomitic quicklime (35 to 40% magnesium oxide). Almost all of the lime available in Ontario is high calcium quicklime, and it may be hard or soft burned. Hard or soft burned classification may be described as follows:

hard-burned	- calcined at high temperature and generally characterized by relatively high density and moderate to low reactivity
soft-burned	- calcined at relatively low temperature and characterized by high porosity and reactivity

Quicklime is also available in a number of more or less standard sizes:

pebble lime	- ranges in size from 18 mm to 6 mm, and is the raw product produced in mist kilns
crushed	- ranges in size from 6 mm to dust
ground	- product resulting from grinding the larger size material and/or screening of the fine size
pulverized	- product resulting from intense grinding

The term "slaking" describes the combination of varying proportions of water (in excess of the stoichiometric quantity) with quicklime to produce a hydrated lime slurry. For maximum efficiency the lime should be slaked at or near optimum conditions which are normally experimentally determined. The way the lime is slaked can mean the difference between a slaked lime of very small average particles size that is slow settling and chemically very reactive, and a hydrate which is much coarser (and possibly incompletely hydrated) that settles rapidly and has a low reactivity. The variables which affect hydrate quality are:

- reactivity of the quicklime
- particle size and graduation of the quicklime
- amount of water
- temperature of slaking
- distribution of water
- agitation
- contact time

Hydration is carried out in a device called a slaker, which may be one of two basic types, (1) detention type - which produces a lime slurry, or (2) paste type - which produces a paste or putty; the only real difference between the two is the amount of water initially added to the quicklime. The detention type is preferred in wastewater treatment plant operations. A detention slaker normally has two compartments; reaction takes place in the first compartment where the dry quicklime is mixed with the optimum amount of water at the desired temperature, producing a high-solids hydrated lime slurry which passes to the second compartment where dilution water is added to produce a slurry of the desired consistency. This second chamber also contains a degritting device.

Hydrated lime is universally used in wastewater treatment operations rather than quicklime because there is a gritty residue produced in the slaking process. With high-quality chemical quicklimes that have been thoroughly calcined and have a loss-on-ignition of 1-1/2 percent or less, the grit content that must be wasted is 1-2 percent of the weight of the quicklime. Included in the grit, along with the carbonate core, are insoluble silicates, etc., all of which are impurities occurring in the limestone. The grit resembles a mass of wet sand-like particles of size

ranging from 6 mm to 100# mesh. Degritting is performed to improve lime quality and reduce abrasion and wear on equipment.

In 1972, under the Canada-Ontario Agreement, a pilot plant program to study the direct use of quicklime for phosphorus removal was initiated. Studies of a similar nature had already been undertaken in the water treatment field (Ward, 1965; Schworm, 1960). The study was carried out at the Wastewater Technology Centre, Environment Canada, where a 1.5 L/s (20 Igpm) primary treatment plant, with a quicklime/dry hydrated lime chemical addition system was built and operated. The study had several objectives, including:

- the investigation of the direct use of unslaked lime as a chemical precipitant for phosphorus removal;
- the development of design criteria for a quicklime system; and
- the comparison of phosphorus removal efficiency between the direct use of unslaked lime and conventional phosphorus removal processes employing slurried hydrated lime.

This report describes the results obtained from the study.

2 EXPERIMENTAL METHODS

2.1 Pilot Plant Equipment

A chemical treatment pilot plant with a hydraulic capacity of 1.5 L/s (20 Igpm) located at the Wastewater Technology Centre (WTC) was used in this study. Raw, degritted sewage obtained from the Burlington Skyway Treatment Plant was used as the influent. A schematic of the pilot plant is shown in Figure 1. The treatment sequence included:

1) Metering hydrated/unslaked lime via a dry feed system into a flash-mix tank where it was contacted with the raw sewage for five minutes.
2) Flocculation by two in-series flocculators for a total residence time of 45 minutes.
3) Clarification in a settling tank which had a mean residence time of 120 minutes and an overflow rate of 2.93 $m^3/m^2 \cdot d$ (600 $Igpd/ft^2$).

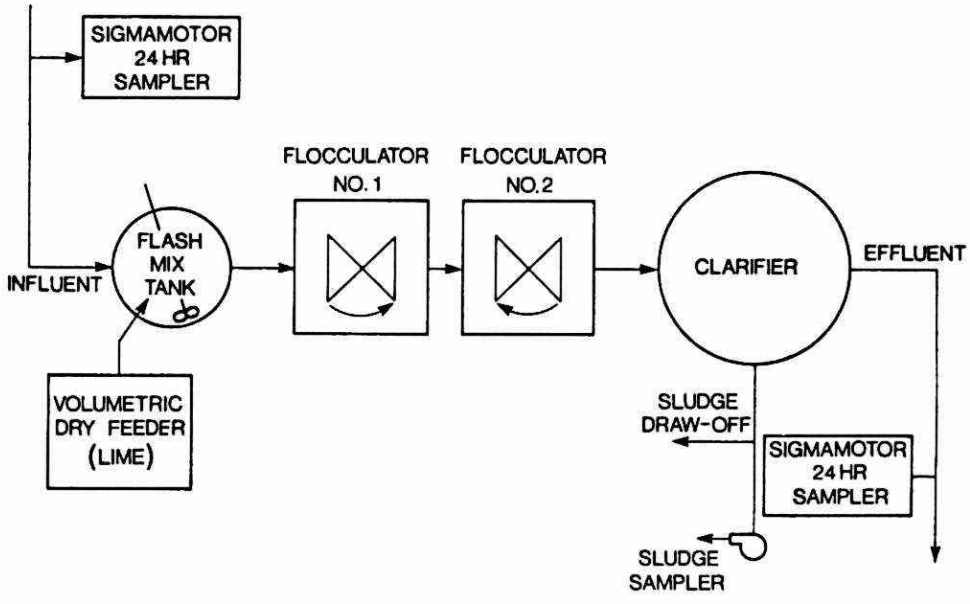

FIGURE 1. CHEMICAL PILOT PLANT SCHEMATIC

The hydrated/quicklime feed unit, which is presented schematically in Figure 2, consisted of a BIF 25-06 volumetric dry feeder and solution tank. The solution tank volume was 2.25 L (0.50 Imperial gallons). Dry lime feed rates ranged from 0.68 to 3.2 kg/h (1.5 to 7 lbs/h) and water

addition rates were 4.5 to 27 L/h (1 to 6 lgph). During the quicklime addition periods the water rate and lime feed rate were manually set to provide the required water to lime ratio. A metering pump was used to control the water rate. The temperature in the slaking reactor was controlled by automatically adjusting the temperature of the incoming slaking water. The agitation in the reactor, provided by a 0.09 kw (1/8 hp) mixer, was sufficient to maintain minus 6 mm (1/4 in) grit in suspension so that it left the reactor with the slaked lime slurry.

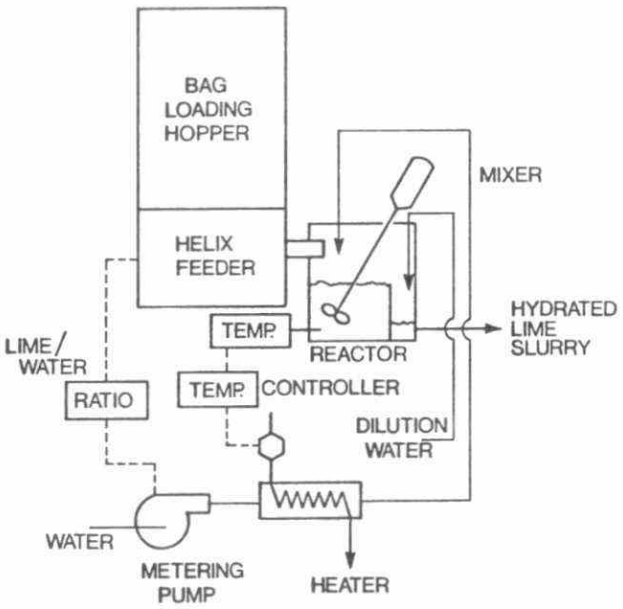

FIGURE 2. PILOT SCALE QUICKLIME HANDLING SYSTEM

2.2 Preliminary Experiments

Prior to the pilot plant experimental runs a number of preliminary experiments were carried out. Jar tests were performed to measure the amounts of quicklime relative to those of hydrated lime required to raise wastewater pH. A hydrated lime stock solution was added incrementally to a series of samples of wastewaters and the pH at equilibrium conditions was measured. The procedure was then repeated for quicklime. The reactivity or speed of slaking is an important chemical property, which must be taken into account in the direct feeding of quicklime to wastewater. To measure the slaking rate, 50 g of quicklime was dropped into a thermos bottle, and

200 g of water at 20°C was rapidly poured in. Then the container was stoppered and continuously agitated. Reaction temperature was monitored continuously until equilibrium. The quantity and size of the grit and residue formed in the slaking process determine the agitation level required in the slaking reactor. They will also have a bearing on equipment lifetime and process reliability. Grit in the quicklime and slaked lime was measured using Tyler sieves. Particle size distribution of the grit in the slaked lime samples was determined by collecting slurry samples from the reactor, sieving the wet slurry, then drying the collected fractions at 105°C in an oven.

2.3 Pilot Plant Test Procedures

The influent and effluent streams of the pilot plant were automatically sampled at hourly intervals, 24 hours a day. From the hourly samples, three 8-hour composite samples were prepared for the period 0 to 8, 8 to 16, and 16 to 24 hours. Twice-daily grab samples of the sludge collected in the clarifier were taken, and a daily composite sample prepared. The analyses performed on these composite samples are summarized in Table 1. Those for BOD_5, suspended solids, total alkalinity, and total hardness were performed according to standard methods (APHA, 1971), while the other analyses were carried out according to procedures described by Traversy (1971). In addition, grab samples of the influent and effluent were collected frequently to monitor pH as a process control parameter. Sludge production was measured and recorded daily.

Along with sample collection, various other measurements and tests were made during the test periods. These tests included: flow measurements (raw sewage, primary sludge, recycle sludge); feed rates of dry lime and dissolution water; sludge settling tests and lime slurry quality (reaction time and neutralization equivalent). Since this was a preliminary study, the pilot plant trials were of relatively short duration. The pilot plant conditions during various operational periods are summarized in Table 2.

2.4 Lime Grades Used in Experiments

Domtar Chemicals Ltd. high calcium soft burned lime was used in all experiments. The lime was supplied in 22.5 kg (50 lb) bags. The

TABLE 1. ANALYTICAL TESTS ON PROCESS STREAMS DURING QUICKLIME EXPERIMENTS

PILOT PLANT INFLUENT AND EFFLUENT	Biochemical Oxygen Demand (BOD_5) Total Organic Carbon (TOC) Suspended Solids (SS) Volatile Suspended Solids (VSS) Total Phosphorus (TP) Total Filtrate Phosphorus (TFP) Total Alkalinity (TA) Total Hardness (TH) Hydrogen Ion Concentration (pH)
PILOT PLANT SLUDGE	Suspended Solids (SS) Volatile Suspended Solids (VSS) Total Phosphorus (TP)

TABLE 2. PILOT PLANT CONDITIONS FOR QUICKLIME EVALUATION

Period	Duration (day/month)	No. days	Type of Lime and pH
1	23/10-03/11	12	baseline
2	06/11-10/11	5	hydrated lime 9.5
3	13/11-17/11	5	quicklime 9.5
4	30/11-03/12	4	quicklime 11.2
5	05/12-14/12	10	hydrated lime 11.2
6	16/12-20/12	5	hydrated lime 11.2
7	08/01-12/01	5	baseline
8	15/01-19/01	5	hydrated lime 9.5
9	22/01-27/01	6	quicklime 9.5
10	07/03-10/03	4	quicklime 11.2
11	13/03-17/03	5	quicklime 9.5
12	19/03-23/03	5	hydrated lime 9.5
13	28/03-01/04	5	baseline

grades of lime examined included: Beachville shaft pulverized quicklime, Beachville rotary kiln quicklime (-10 mesh), Beachville rotary crushed quicklime and Beachville chemical hydrate. Tyler screen analyses and pertinent physical properties of these limes are presented in Tables 3 and 4, respectively. These quicklimes may be related to quicklimes in general by comparing these data with those presented in Table 5.

TABLE 3. MESH (TYLER) ANALYSES OF LIME GRADES

Mesh (Tyler)	Shaft Pulverized	Rotary Kiln (-10 mesh)	Rotary Crushed	Chemical Hydrate
	average percent passing			
-1/4 inch			100	
10		100	75	
28	100	68		
48	97	48	30	100
100	20	26	20	99.9
150		9		
200	15	1	15	96.0
325				93.0

TABLE 4. ASTM SLAKING RATES OF LIME GRADES

Physical Property	Shaft Pulverized	Rotary Kiln (-10 mesh)	Rotary Crushed	Chemical Hydrate
Slaking rate temp. rise in 30 sec.	12°C	28°C	40°C	-
Total temp. rise	35°C	40°C	48°C	
Active slaking time	7 min	2 min	2 min	-
Emley plasticity	250	500	500	140

TABLE 5. CHARACTERISTICS OF MAIN GRADES OF QUICKLIME (CARR, 1976)

GRADES	CALCIUM CONTENT
High Calcium	>88% CaO
Medium Calcium	75 - 88% CaO
Low Calcium	<60 - 76% CaO
Dolomitic	51 - 58% CaO 35 - 41% MgO
Magnesium	5 - 35% MgO
Dolomitic Lime could also be classed as a low calcium lime	

FORM	PARTICLE SIZE
Lump	3" - 8" and smaller
Lump Crushed	1/2" - 2-1/2" to dust
Pebble	1/4" - 1-1/2" and smaller to dust
Pellet	20 to 100 mesh
Ground	-8 to -100 mesh
Pulverized	+100 to -200 mesh

BURNED OR CALCINED	CALCINATION TEMPERATURE DEG. F	(1) SLAKING CHARACTERISTICS
Soft	Calcined just above the decomposition temperature necessary -- 1800 to 2400° F in a minimum time.	Very quick slaking and temperature rise
Normal	Calcined at about 2400 to 2600° F in a minimum time.	Fast to medium slaking and temperature rise
Over	Calcined at 2500 to over 2600° F. If lower, then time would be longer.	Medium to slow slaking and temperature rise
Hard	Calcined above 2600° F. If at a lower temperature, time would be longer.	Slow to very slow slaking and temperature rise

TYPE OF REACTION FOR DIFFERENT GRADES OF LIME AT 4 TO 1 RATIO (1)

CALCIUM OXIDE %	BURNED OR CALCINED	SLAKING REACTION	TIME MINUTES	TEMPERATURE RISE	RANGE IN DEG. F (2)
High Calcium	Soft	Very Quick	1 - 3	Very High	90 - 100
	Normal	Medium	8 - 16	High	85 - 100
	Over to Hard	Medium to Slow	20 - 35+	High to Med. (3)	<80 - 90
Medium Calcium	Soft	Quick to Medium	5 - 8	High to Med. (3)	75 - 92
	Normal	Medium	15 - 35	Medium	70 - 92
	Over to Hard	Slow	20 - 40+	Med. to Low (3)	<50 - 80
Low Calcium	Soft	Quick to Medium	5 - 10	Medium	<60 - 75
	Normal	Medium	20 - 40	Med. to Low (3)	<50 - 70
	Over to Hard	Slow to Very Slow	40 - 60+	Low to Very Low (3)	<10 - 40+
Dolomitic	Soft	Quick to Medium	5 - 10	Low	55 - 61
	Normal	Medium	8 - 15	Low	<40 - 51
	Over to Hard	Slow to Very Slow	40 - 60+	Very Low	<10 - 30+

(1) Time of calcination, type of kiln, composition of limestone and the composition of the surrounding atmosphere (CO_2 content in kiln), are all factors in the type of burned lime produced, as to reactivity, etc. At a lower ratio (say 2.5 - 1) reaction could be quicker or at least similar. Air slaking will increase slaking time and decrease the temperature rise.

(2) Insulated reaction, with no insulation, the temperature would be less.

(3) According to the heat loss, due to slower slaking and/or to the calcium content.

3 RESULTS AND DISCUSSION

3.1 Preliminary Experiments

As a basis of comparison, jar tests were conducted using hydrated lime and quicklime to raise the pH of raw wastewater. The results of two representative jar tests are illustrated in Figures 3(a) and 3(b). These tests indicated that the quicklime requirement averaged 79 percent of the hydrated lime requirement for an equivalent pH increase, compared with 75 percent from theoretical considerations. Since the available lime index was the same for the hydrated lime and quicklime used in the experiments, the increased relative quicklime requirement most probably resulted from incomplete slaking of the quicklime.

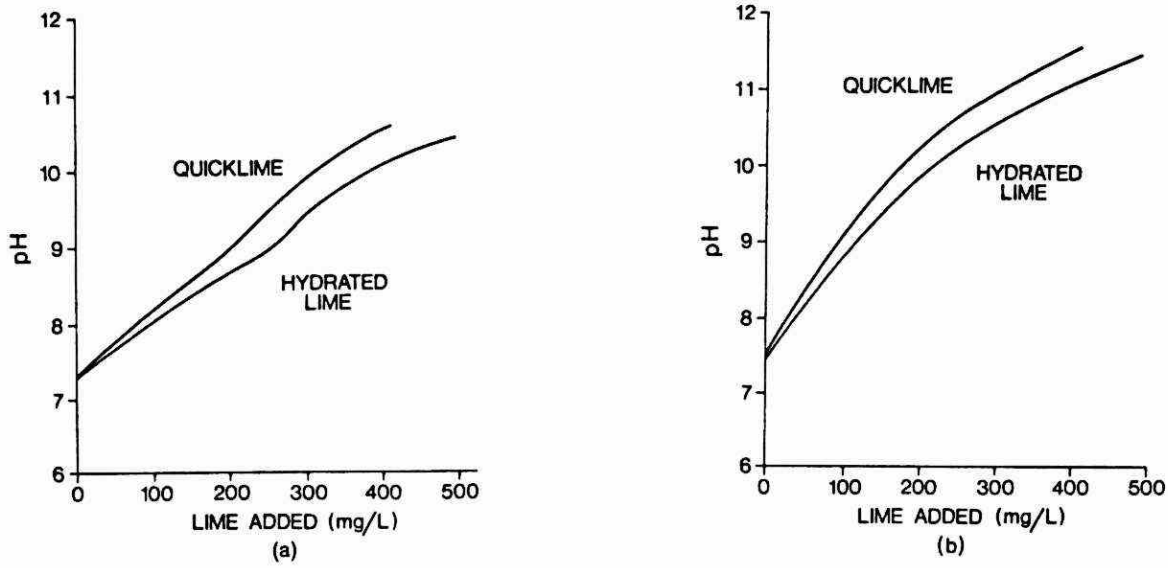

FIGURE 3. COMPARISON OF HYDRATED AND QUICKLIME DOSAGES IN TWO REPRESENTATIVE JAR TESTS

In the direct use of dry quicklime, the slaking speed is an important factor. The hydration reaction should be complete before the lime slurry contacts the wastewater, as slaking rate is very dependent on the lime to water ratio and reaction temperature. Any unreacted quicklime added to the wastewater is lost, as that lime would settle out in the clarifier before it had reacted. This effect would occur because of the relatively low wastewater temperature and lime to water ratio. Generally speaking, a desirable grade of quicklime is one where the hydration reaction is essentially complete within four or five minutes.

In a series of tests on slaking rate it was found that hydration was essentially complete within 3 minutes, and that initial temperature (20 to 40°C) and particle size distribution (shaft pulverized, rotary kiln (-10 mesh) and rotary crushed) had relatively little effect on hydration. The results of typical tests on hydration rate are presented in Figures 4 and 5.

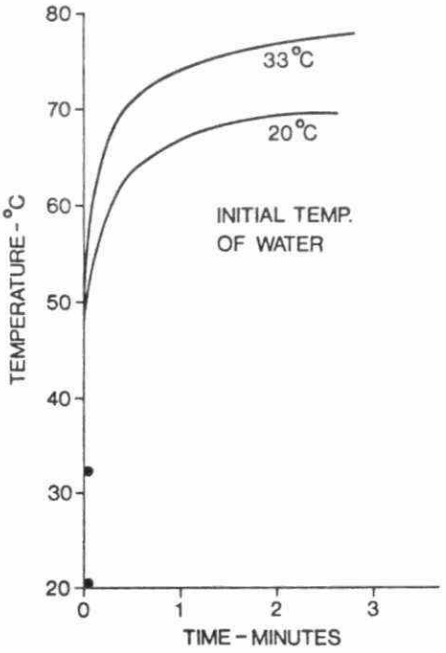

FIGURE 4. EFFECT OF INITIAL TEMPERATURE ON SLAKING RATE

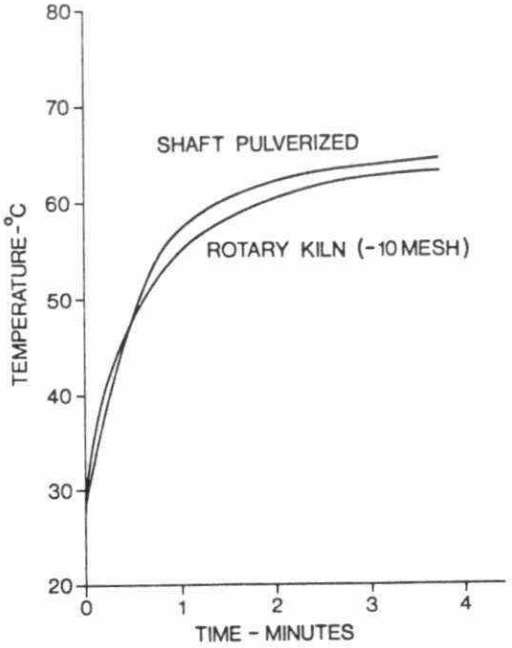

FIGURE 5. RELATIVE SLAKING RATES OF LIME GRADES

Grit and residue remaining in the slaked quicklime is also an important factor to be examined when considering the use of dry quicklime. The grit size determines the mixing level required in the slaking reactor and may also have a significant impact on the lifetime of the rotating equipment and pumps in downstream processes. Sieve tests were conducted on various quicklime grades and on the grit which resulted; examples of the experimental data from representative tests are presented in Figures 6(a) and 6(b). It was found that particle size distribution generally followed the original quicklime-grade particle size fraction. In most of the experiments, the grit which remained on the sieves was two to three percent of the initial quicklime fed. Thus the mixing level and, indirectly, equipment wear would increase with increasing average particle size of a quicklime-grade.

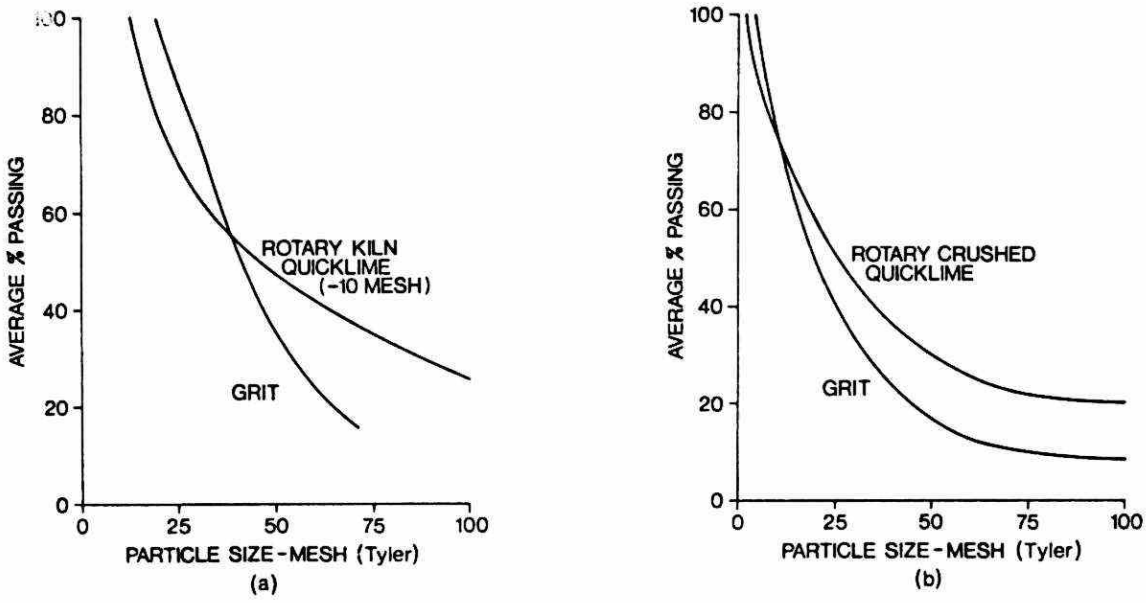

FIGURE 6. EXAMPLES OF SCREEN ANALYSES OF QUICKLIME AND GRIT

3.2 Pilot Plant Tests

Initial experiments with the quicklime feed system resulted in only a very small temperature rise in the solution pot. Because of this only partial reaction occurred even though the water to lime ratio was between 5:1 and 10:1. The rate of heat loss from the reactor was too great to sustain the reaction. To compensate for the heat losses, the reactor was insulated and a heating unit was inserted in the water inlet of the slaker. Reactor temperature could then be controlled by adjusting the temperature of the incoming water. All subsequent experiments reported were conducted with a water to lime ration of 5:1 and a reactor temperature of 66°C (150°F). The grade of quicklime used was rotary kiln quicklime (-10 mesh).

The pilot plant experiments were designed to evaluate, at both the low lime treatment level (pH 9.5) and the high lime treatment level (pH 11), the effectiveness of dry quicklime relative to hydrated lime. The factors used in this assessment were: (1) lime dose required; (2) phosphorus removal; and (3) general treatment capabilities. In all, there were 13 experimental periods of approximately one to two weeks duration each.

The average raw wastewater characteristics for each experimental

period are presented in Table 6. Table 7 summarizes, for each test period, the type of lime used and the quantity of lime required to achieve the desired pH level. The values of lime quantity reported are average values of the daily consumption data. The data confirm bench test results and show that the relative quicklime to hydrated lime ratio is 75 to 80 percent at the low lime treatment level, and 79 to 81 percent at the high lime treatment level.

TABLE 6. RAW SEWAGE CHARACTERISTICS

PERIOD*	BOD_5 mg/L	TOC mg/L	SS mg/L	VSS mg/L	TP mg/L	TFP mg/L	TA mg/L	TH mg/L	pH -
1	134	27.6	187	136	5.2	2.4	238	222	7.6
2	77	12.9	210	73	2.6	0.9	260	235	-
3	129	15.1	359	126	5.0	1.1	313	245	-
4	92	13.4	136	100	4.1	2.6	226	243	7.8
5	77	15.5	130	92	3.1	1.9	233	272	7.7
6	89	12.9	111	83	3.5	2.8	245	291	7.6
7	139	13.0	163	123	5.5	3.3	243	266	7.5
8	110	12.9	126	93	5.4	3.7	227	266	7.6
9	82	16.9	119	89	4.9	3.4	219	259	7.4
10	67	12.0	100	80	3.3	2.1	216	300	7.3
11	55	9.7	124	78	2.6	1.5	212	320	7.3
12	50	15.1	97	76	2.7	1.8	220	337	7.6
13	77	15.8	139	99	3.4	2.0	225	323	7.3

*See Table 2 for specific times.

TABLE 7. QUICKLIME VS. HYDRATED LIME REQUIREMENT TO ACHIEVE DESIRED pH LEVEL

PERIOD*	pH	LIME TYPE	QUANTITY REQUIRED kg/d	RELATIVE QUICKLIME REQUIREMENT %
1	-	baseline	-	-
2	9.5	hydrated	31.1	-
3	9.5	quick	23.2	75%
4	11.2	quick	58.1	79%
5	11.2	hydrated	73.0	-
6	11.2	hydrated	73.5	-
7	-	baseline	-	-
8	9.5	hydrated	29.8	-
9	9.5	quick	22.8	77%
10	11.2	quick	59.4	80%
11	9.5	quick	24.1	80%
12	9.5	hydrated	30.1	-
13	-	baseline	-	-

*See Table 2 for specific times.

TABLE 8. COMPARISON OF REMOVAL CHARACTERISTICS (PHOSPHORUS)

		PERIOD*	TOTAL PHOSPHORUS (mg/L)			FILTERED PHOSPHORUS (mg/L)		
			IN	OUT	% REMOVAL	IN	OUT	% REMOVAL
	Baseline	1	5.2	3.8	27	2.4	2.4	-
		7	5.5	4.6	16	3.3	3.4	-
		13	3.4	2.9	15	2.0	2.1	-
LOW LIME (pH 9.5)	Hydrated Lime	2	2.6	1.8	31	0.9	1.0	-
		8	5.4	1.8	67	3.7	1.0	73
		12	2.7	1.2	56	1.8	0.8	56
	Quicklime	3	5.0	1.9	62	1.1	0.9	18
		9	4.9	2.0	59	3.4	1.1	68
		11	2.6	0.8	69	1.5	0.5	66
HIGH LIME (pH 11.2)	Hydrated Lime	5	3.1	0.4	87	1.9	0.2	89
		6	3.5	0.5	86	2.8	0.3	89
	Quicklime	4	4.1	0.5	88	2.6	0.2	92
		10	3.3	0.3	91	2.1	0.2	90

*See Table 2 for specific times

The phosphorus removal characteristics of the quicklime and hydrated lime additions are summarized in Table 8. Quicklime proved to be slightly more efficient for total and filtered phosphorus removal than hydrated lime (10 percent better at the low lime rate and 3 percent better at the high lime rate). Table 9 presents the biochemical oxygen demand and suspended solids measured in the influent and also the percentage removal achieved during the hydrated and quicklime additions. The quicklime additions proved to be slightly better for suspended solids removal than hydrated lime, with very little difference observed for biochemical oxygen demand.

TABLE 9. COMPARISON OF REMOVAL CHARACTERISTICS (BIOCHEMICAL OXYGEN DEMAND AND SUSPENDED SOLIDS)

		PERIOD*	BIOCHEMICAL OXYGEN DEMAND (mg/L)			SUSPENDED SOLIDS (mg/L)			VOLATILE SUSPENDED SOLIDS (mg/L)		
			IN	OUT	% REMOVAL	IN	OUT	% REMOVAL	IN	OUT	% REMOVAL
	Baseline	1	134	76	44	187	69	63	136	60	56
		7	139	82	41	163	67	59	123	52	58
		13	77	47	39	139	77	44	99	60	39
LOW LIME (pH 9.5)	Hydrated Lime	2	78	49	38	210	47	78	73	27	63
		8	110	27	75	126	39	69	92	21	78
		12	50	27	46	97	41	58	76	20	73
	Quicklime	3	129	58	55	359	52	85	126	28	78
		9	82	35	58	119	45	62	89	23	74
		11	55	25	54	124	36	71	78	17	79
HIGH LIME (pH 11.2)	Hydrated Lime	5	78	20	74	130	56	60	92	17	81
		6	89	20	77	111	31	72	83	10	88
	Quicklime	4	93	28	69	136	50	63	100	14	86
		10	67	15	78	100	26	74	80	10	88

* See Table 2 for specific times.

Sludge production for low and high lime systems are summarized in Table 10. Sludge production increased five-fold at low lime conditions and seven-fold at high lime conditions over baseline conditions. On the whole, effluent and removal data demonstrate that dry quicklime may be used in primary treatment of municipal wastewater in place of hydrated lime.

TABLE 10. SLUDGE PRODUCTION

		PERIOD*	SLUDGE FLOW (L/d)	SLUDGE CONC. (mg/L)	SLUDGE PRODUCTION (kg/d)	RELATIVE AVE. % INCREASE IN SLUDGE PRODUCTION OVER BASE-LINE
	Baseline	1	318	45 200	14.4	
		7	123	47 400	5.8	
		13	132	84 600	11.2	
LOW LIME (pH 9.5)	Hydrated Lime	2	345	106 000	36.6	
		8	590	98 600	58.2	532
		12	645	110 000	71.0	
	Quicklime	3	227	147 000	33.4	
		9	636	115 000	73.1	545
		11	540	117 000	63.2	
HIGH LIME (pH 11.2)	Hydrated Lime	5	962	83 200	80.0	
		6	831	101 000	83.9	787
	Quicklime	4	872	86 400	75.3	
		10	1303	56 200	73.2	713

*See Table 2 for specific times

4 HANDLING OF QUICKLIME FOR PHOSPHORUS REMOVAL

The equipment design and sizing parameters to be used for dry feeding of quicklime requires some consideration. Quicklime feed equipment was examined with respect to the following factors: quicklime storage, particle size, reactivity of quicklime, water to lime ratio, temperature of slaking, contact time and agitation.

4.1 Quicklime Storage

Storage units for quicklime must be water and airtight, as quicklime is subject to slaking by moist air and deteriorates in storage at a much more rapid rate than lime. Quicklime is commercially supplied in bags or in bulk. Under good storage conditions, with multiwall moisture-proofed bags, quicklime has a storage life of three months. If bulk storage is used, the silo should be of sufficient size to have an on-hand storage capacity of seven days at all times, and a total storage capacity which is 50 percent greater than the minimum truck delivery (15 m^3). The most popular storage unit is a cylindrical steel silo with a cone bottom (cone angle 60 degrees or greater). The silo should be equipped with the following accessories: a dust collector (28 m^2 filter area); relief valve, high level, refill, and low level indicators; an inspection hatch and a fill pipe with cyclone inlet.

The procedures for the selection of silo and bag feeders are readily available (National Lime Association, 1976) and thus are not detailed here. Feeders generally have a variable feed capability and are chosen to have a maximum feed rate of 1.5 times the normal daily usage rate. For silos, it has been found that gyrating bin bottoms, and vibrators coupled to variable flow volumetric feeders provide trouble-free operation. Increasing pitch helical screws with mechanical agitators, such as the BIF volumetric feeder, provide excellent results in bag operations.

4.2 Quicklime Particle Size

The experience gained during this study confirmed the conventional wisdom that quicklime is easier to feed than hydrated lime. Large size grades of quicklime were also less likely to air slake, and were easier to feed than small size grades of quicklime; thus larger size grades of quicklime are preferred. However, with large size grades, the resultant grit

particle size is increased along with its component problems. The grit problems caused by large grades of quicklime may be minimized if a rod or ball mill is used as the reactor vessel. Such a mill will provide the agitation required for slaking and grind the large grit particles into a fine powder. The technique was successfully demonstrated at an acid-mine-drainage waste treatment plant (Rivett and Oko, 1972; Denver Equipment Company, 1970) using rotary crushed quicklime, or pebble quicklime, and a 3 feet ($\sim$1 m) diameter Denver ball mill. However ball mills are relatively expensive and a lime demand of 20 000 kg/d is required before ball mill reactors should be considered. When the demand is less than 20 000 kg/d, a small size grade quicklime, such as the -10 mesh quicklime examined in the experimental phase of the study, should be used with a stirred tank reactor.

4.3 Quicklime Reactor

The configuration and capacity of the slaking reactor depends on the following factors: water to lime ratio, reactor residence time, agitation level and slaking temperature. The experimental results showed that to successfully feed dry quicklime to a reaction vessel without using a slaker, the water to lime ratio must be in the range of 6:1 to 10:1, and close to 7:1 if problems with slurry flow and pumping are to be avoided. This water to lime ratio results in a major portion of the sensible heat produced in the slaking reaction leaving the reactor in the slaked lime slurry, and a sufficiently high reactor temperature (55 to 65°C) is not developed. To initiate the reaction and maintain the reactor temperature, the incoming water must be heated. This may be accomplished by recovering the sensible heat in the slurry leaving the reactor with a plate coil heat exchanger (about 1.5 m^2 of heat transfer area) immersed in a second compartment through which the slaked lime passes. The make-up water is passed through the coil plate and is heated before it enters the slaking compartment.

The use of the wastewater itself, in place of soft water, in the slaking reaction should be considered. Experiments reported by Carr (1976) and presented in Table 11 demonstrate that slaking is not affected by the use of wastewater in the slaking reactor. Thus the use of wastewater as slaking water is recommended. The slaking water/slaked slurry retention time for high calcium quicklimes (CaO greater than 88%) should be 25 to 30 minutes in the slaking compartment and 20 to 25 minutes in the heat exchange compartment. The agitation requirement for the two compartments may be

obtained from Table 12, where agitation horsepower is presented as a function of slurry concentration.

TABLE 11. SLAKING WITH WASTEWATERS (CARR, 1976)

WASTEWATER DESCRIPTION	WASTEWATER ANALYSIS				SLAKING TESTS											
					"SOFT" TAP WATER						WASTEWATER					
	T.D.S. %	Cl^- %	$SO^{=}$ %	RATIO WATER TO LIME	TIME MIN.	TEMP INIT. °F	RISE °F	VIS-COSITY cp	GRIT RESI-DUE %	RATIO WATER TO LIME	TIME MIN.	TEMP. INIT. °F	RISE °F	VIS-COSITY cp	GRIT %	RESI-DUE %
1) Brackish	2.9	1.3	0.19	4-1	3	62	101	15,000	7.0	3½-1	2	93	110+	450	4.5	19.0
a) Brackish	2.9	1.3	0.19	4-1	3	62	101	15,000	7.0	4-1	2	128	86+	1,000	4.0	16.0
b) Brackish	1.45	0.65	0.095	4-1	3	62	101	15,000	7.0	3-1	2	92	120+	6,000	2.5	11.0
c) Brackish	1.45	0.65	0.095	4-1	3	62	101	15,000	7.0	3½-1	2	72	108+	1,750	3.0	16.0
2) $CaCl^2$ Brine	4.0	2.6	0.001	4-1	3	65	93	8,000	7.0	4-1	2	74	98	600	19.0	6.0
a) $CaCl^2$ Brine	4.0	2.6	0.001	6-1	2	115	60	800	3.0	6-1	1	119	65	160	12.0	8.0
3) Cooling	0.08	0.006	0.03	4-1	2	74	99	20,000	5.0	4-1	3	74	94+	2,500	2.0	3.5
a) Cooling	0.08	0.006	0.03	4-1	2	74	99	20,000	5.0	3-1	2	72	128+	8,500	1.5	2.5
4) Lake Morgan,	1.4	0.011	0.08	4-1	2	74	99	20,000	5.0	4-1	3	75	99	600	2.0	7.0
a) Arizona	1.4	0.011	0.08	4-1	2	74	99	20,000	5.0	3-1	2	72	128+	15,000	2.0	3.0
5) Reactor -	2.0	-	0.10	4-1	5	56	94	4,000	5.0	3¼-1	3	75	107+	4,000	2.0	8.0
a) Clarifier	2.0	-	0.10	4-1	5	56	94	4,000	5.0	3½-1	4	107	96	1,100	5.0	6.0
6) Scrubber	0.5	-	-	4-1	2	62	101	15,000	7.0	3½-1	5	70	99	2,000	3.0	11.0
7) Scrubber	0.12	0.012	0.03	4-1	5	69	98	5,000	5.0	4.9-1	3	128	74+	2,000	2.5	2.5
a) Scrubber	0.12	0.012	0.03	4-1	4	70	98	3,000	5.5	4-1	3	100	92+	800	3.5	3.5
b) Scrubber	0.12	0.012	0.03	4-1	4	70	98	3,000	5.5	3¼-1	3	98	114	4,000	3.0	2.0
c) Scrubber Treat	0.05	0.003	0.004	4-1	5	69	98	5,000	5.0	4-1	5	74	99	1,400	2.0	3.0
8) Sec.Sew.Eff.	0.12	0.005	-	3½-1	6	72	94	3,000	6.0	3½-1	6	72	95	1,500	4.0	1.0
9) Sec.Sew.Eff.	0.05	0.011	-	4-1	20	70	98	4,000	6.5	4-1	18	70	96+	1,000	1.0	6.5
10) Sec.W.W.Eff.	0.123	0.03	0.065	4-1	1	72	108	60,000	3.5	4-1	2	71	99+	3,000	4.0	5.0

TABLE 12. AGITATION REQUIREMENTS

SLURRY CONCENTRATION (wt %)	AGITATION FOR SLAKING (kw/m^3)	AGITATION FOR STORAGE AND HEAT EXCHANGE (kw/m^3)
1	0.163	0.032
5	0.163	0.032
10	0.163	0.032
15	0.197	0.058
20	0.214	0.082

The control strategy of the quicklime slaking process may be based on (1) preparing a constant strength slurry and metering it into the process at a variable rate according to process requirements, or (2) preparing a variable strength slurry according to process requirements and feeding it at a constant rate. The former control technique is preferred because fewer control components are required. Thus the process would be controlled by (1) setting the lime feed rate, (2) setting the water feed rate according to the water to lime ratio specified, and (3) setting the reaction temperature. By using a temperature controller, whose sensor is immersed in the slaking compartment, the reactor temperature can be maintained by adjusting the fraction of the total slaking water which passes through the heat exchanger.

4.4 Cost of a Quicklime Feed System

The cost of a quicklime feed system may be estimated for a given treatment plant size by using Tables 13 and 14. Table 13 provides lime requirements for various waste treatment plant sizes based on a lime dose of 200 mg/L. Table 14 provides cost information for hydrated and quicklime units in terms of silo storage requirements and lime feed rates. The quicklime unit data (QL in Table 14) used information generated by this study for equipment sizing. The hydrated lime unit data (HL in Table 14) is based on conventional design methodology (Fahlenbock, 1973).

From the data it can be shown that, provided lime usage exceeds 6500 kg/d, a quicklime system is less expensive in terms of total cost (consisting of operating and capital cost) than a hydrated lime system.

TABLE 13. LIME REQUIREMENTS* VS. PLANT SIZE

PLANT SIZE m^3/d (MIGD)	HYDRATED LIME			QUICKLIME			SLURRY FLOW (7 TO 1 RATIO) L/s
	kg/d	m^3/h	7 d STORAGE m^3	kg/d	m^3/h	7 d STORAGE m^3	
28 000 (1)	900	0.08	13.1	675	0.03	5.4	4.5
113 000 (4)	3600	0.31	52.5	2700	0.12	21.7	18.2
283 000 (10)	9100	0.78	131.3	6750	0.31	54.7	4.5
566 000 (20	18200	1.57	262.6	13500	0.62	108.6	9.1

*Based on dosage of 200 mg/L.

TABLE 14. LIME FEED EQUIPMENT COST AS A FUNCTION OF FEED RATE

DESCRIPTION	LIME USED (kg/day)			
	900	3600	9100	18 200
Dry feeder, slurry/reactor tank, controls metering pump, mixer (common to HL and QL units)	$23 000	$24 000	$25 000	$28 000
Ball mill modified for this application (QL unit only)	$18 000	$18 000	$18 000	$18 000
Heat exchanger, mixer secondary tank, and controls (QL unit only)	$10 900	$11 200	$12 400	$15 500

	SILO CAPACITY (m^3)				
	28	57	85	113	142
Silo building and related accessories (common to HL and QL units)	$17 000	$26 000	$32 000	$37 000	$42 000

QL = Quicklime
HL - Hydrated lime

REFERENCES

APHA, AWWA, and WPCF, Standard Methods for the Examination of Water and Wastewater, 13th Edition (1971).

Bernhoff, R., "The Role of Lime and Dolomite in the Treatment of Municipal Waste Water:, International Lime Conference, Berlin (May, 1974).

Black, S.A. and Lewandowski, W., "Phosphorus Removal by Lime Addition to a Conventional Activated Sludge Plant", Ontario Water Resources Commission, Research Publ. No. 36 (1969).

Boynton, R.S., Chemistry and Technology of Lime and Limestone, John Wiley and Sons, Inc. (1966).

Carr, R.L., "Wet-Slaking Speeds Lime Reactivity", Water and Sewage Works 123(8): 84 (1976).

Convery, J.J., "Treatment Techniques for Removing Phosphorus from Municipal Wastewaters", Water Pollution Control Research Series #17010-01/70 (1970).

Denver Equipment Company, "Flowsheet Study for Lime Slaking", Deco Trefoil, p. 17 (Fall Issue, 1970).

Fahlenbock, T., "Lime-Storage, Handling and Feeding", Water and Pollution Control, 111(3): 39 (1973).

Hirsch, A.A., "Dry Feed of Ground Quicklime without a Slaker", J. Am. Water Works Assoc. 54: 1531 (1962).

Jones, D.W. "Pulverized Quicklime for Water Softening", Water and Sewage Works, 104(6): R216 (1957).

Menar, A.B. and Jenkins, D., "Calcium Phosphate Precipitation in Wastewater Treatment", Environmental Protection Technology Series, EPA-R2-72-064 (1972).

Minton, G.R. and Carlson, D.A., "Primary Sludges Produced by the Addition of Lime to Raw Waste Water", Water Research, 7: 1821 (1973).

National Lime Association, Lime Handling, Application and Storage, Bulletin No. 213 (1976).

Rivett, L.S. and Oko, U.M., "Acid Neutralization Doesn't Cost Much", Water and Wastes Eng., 9(11): B12 (1972).

Schworm, W.C., "Low Temperature Liquid Lime Slaking at Howard Bend Treatment Plant", J. Am. Water Works Assoc., 52: 948 (1960).

Sheehy, J.W. and Evans III, F.L., "Tertiary Treatment for Phosphorus Removal at Ely, Minnesota AWT Plant", Environmental Protection Technology Series, EPA 600/2-76-082 (1976).

Traversy, W.J., "Methods for Chemical Analysis of Water and Wastewaters", Water Quality Division, Department of Fisheries and Forestry, Ottawa (1971).

Ward, F.L., "Unslaked Lime - Its Direct Use in Water Treatment", Water Works and Wastes Eng., 38 (Dec., 1965).

ACKNOWLEDGEMENTS

The study was conducted by Dr. B.P. LeClair while an employee of Environment Canada at the Wastewater Technology Centre.

The report was written under contract by M.T. Fahlenback and Dr. B.P. LeClair of Control and Metering, Toronto.

TD
758.5
.P56
U57
1980

Unslaked lime : it's direct use in phosphorus removal processes /
78922